

LOW COST, HIGH AVERAGE POWER, HIGH BRIGHTNESS SOLID STATE LASER

This invention is a Continuation-in-Part application of Ser. No. 08/295,283, filed Aug. 24, 1994 and now U.S. Pat. No. 5,434,875.

This invention relates to laser systems and in particular to high power, high brightness solid state laser systems.

BACKGROUND OF THE INVENTION

There is a growing need for reliable, economical X-ray sources for X-ray lithography. It is known that X-ray sources can be produced by illuminating certain metals with very high brightness laser pulses. Required brightness levels are in the range of 10^{11} to 10^{13} W/cm² for projection lithography and 10^{13} to 10^{15} W/cm² for proximity lithography. To meet future commercial lithography needs, average laser power requirements are about 500 Watts for projection and 1000 Watts for proximity. In addition the lithography process needs call for an X-ray spot diameter of about a few 100 μ m. Designing a laser to meet these requirements involves solving several current problems. The first is the correction of aberrations due to thermal distortion and self focusing in the laser rod. This problem is currently being dealt with by utilizing a Stimulating Brillouin Scattering (SBS) cell to remove these aberrations. SBS cell materials perform efficiently for laser pulses of several nanoseconds or greater. For nanosecond laser pulses, the energy needed to achieve the required brightness is 10 to 30 Joules per pulse and the repetition rate needed to achieve the required power is 100 to 30 hertz. This high pulse energy design creates two additional problems. The amount of debris produced by nanosecond pulsed lasers focused on solid targets, when operated at the required brightness and power levels, is unacceptable. (Studies done by Rutherford and CREOL indicate that the debris level from metal targets is related to the pulse duration. The shorter the pulse duration the lower the debris level.) There is a research program underway to reduce debris by using solid xenon as an X-ray target, but it is at a very early stage and costs are uncertain. The final problem is the cost of the X-ray lithography system.

Flash lamp pumped lasers involve high maintenance costs. Maintenance costs can generally be reduced by pumping with diode lasers. Unfortunately, laser diodes required for the 10 joule per pulse 100 Hz lasers costs millions of dollars.

What is needed is a laser system that meets the needs of X-ray lithography to provide 1) high average power and high brightness, 2) low debris levels and 3) low capital and maintenance cost.

SUMMARY OF THE INVENTION

The present invention provides a high average power, high brightness solid state laser system. We first produce a seed laser beam with a short pulse duration and a pulse frequency in excess of 1,000 pulses per second. A laser amplifier amplifies the seed beam to produce an amplified pulse laser beam which is tightly focused to produce pulses with brightness levels in excess of 10^{11} Watts/cm². Preferred embodiments produce an amplified pulse laser beam having an average power in the range of 1 kW, an average pulse frequency of 12,000 pulses per second with pulses having brightness levels in excess of 10^{14} Watts/cm² at a 20 μ m diameter spot which is steered rapidly to simulate a larger spot size. These beams are useful in producing X-ray

sources for lithography.

In one preferred embodiment, the seed beam is produced in a mode locked Nd:YAG oscillator pumped by a diode array with the frequency of the pulses being reduced by an electro-optic modulator. In a second preferred embodiment, the seed beam is Q switched and includes a Pockels cell for cavity dumping. In a third preferred embodiment, the short duration high frequency pulses for the seed beam is produced by cavity dumping of a short cavity resonator.

As compared with prior art high brightness lasers, we have achieved our very high brightness by reducing the pulse duration by about 2 or 3 orders of magnitude, from a few ns to 100 ps or less and by focusing on a very small spot, but we are able to simulate a much larger spot by very rapidly steering our high average power beam over the area we need.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a drawing showing the principal features of a preferred embodiment of the present invention for producing high brightness pulse laser beams useful for X-ray lithography.

FIGS. 1A, 1B and 1C are qualitative representations of the pulse shape at various stages of the embodiment shown in FIG. 1.

FIG. 2 is a drawing showing in greater detail a first portion of the embodiment of FIG. 1.

FIG. 3 is a drawing showing in greater detail a second portion of the embodiment shown in FIG. 1.

FIG. 4 is a drawing showing the amplifier pumping configuration using laser diodes for the embodiment shown in FIG. 1.

FIG. 5 is a drawing showing a cluster of tightly focused spots.

FIG. 6 is a drawing showing the details of the second preferred seed laser system.

FIGS. 7A and B are drawings showing the details of the third preferred seed laser system. They show the effect of turning on a Pockels cell.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

A preferred embodiment of the present invention can be described by reference to FIGS. 1, 2 and 3. As shown in FIG. 1, this embodiment consists of a mode locked Nd:YAG laser oscillator 2, a pulse spacing selector 20, a beam expander 22, a polarizing beam splitter 26, a double pass amplifier section 24 and a beam steering PZT 48 on which amplifier folding mirror 38 is mounted. The output of amplifier 24 is focused to a tiny spot on moving copper tape target 27. FIG. 2 describes the seed laser section of the embodiment which is for producing very short duration pulses at a very high repetition rate and FIGS. 3 and 4 describe the amplifying section for amplifying the pulses to produce a pulsed laser beam with an average power level of about 1 kW with pulses at brightness levels in the range of 10^{14} W/cm² on spot sizes of about 20 μ m diameter. And finally, FIG. 5 shows the result of a beam steering mechanism to generate a cluster of few 20 μ m spots 52 over a 500 μ m diameter circular area on a metal target.

FIRST PREFERRED SEED LASER

FIG. 2 is a diagram of a Nd:YAG mode locked oscillator type laser device 2. A Nd:YAG polished rod 4 (3 mm diameter and 2.5 cm long) is longitudinally pumped by a 5